US009272704B2

(12) **United States Patent**
Sato et al.

(10) **Patent No.: US 9,272,704 B2**

(45) **Date of Patent: Mar. 1, 2016**

(54) **HYBRID VEHICLE HAVING BOOST CONVERTER AND CONTROL METHOD OF A HYBRID VEHICLE HAVING A BOOST CONVERTER**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/592,349**

(22) Filed: **Jan. 8, 2015**

(65) **Prior Publication Data**

US 2015/0210267 A1 Jul. 30, 2015

(30) **Foreign Application Priority Data**

Jan. 27, 2014 (JP) 2014-012828

(51) **Int. Cl.**

B60L 9/00	(2006.01)
B60W 20/00	(2006.01)
B60L 11/12	(2006.01)
B60L 11/08	(2006.01)
B60L 11/18	(2006.01)
B60W 10/06	(2006.01)
B60W 10/08	(2006.01)

(52) **U.S. Cl.**

CPC ***B60W 20/1088*** (2013.01); ***B60L 11/08*** (2013.01); ***B60L 11/12*** (2013.01); ***B60L 11/1803*** (2013.01); ***B60L 11/1814*** (2013.01); ***B60W 10/06*** (2013.01); ***B60W 10/08*** (2013.01); *B60L 2210/14* (2013.01); *B60L 2210/42* (2013.01); *Y10S 903/93* (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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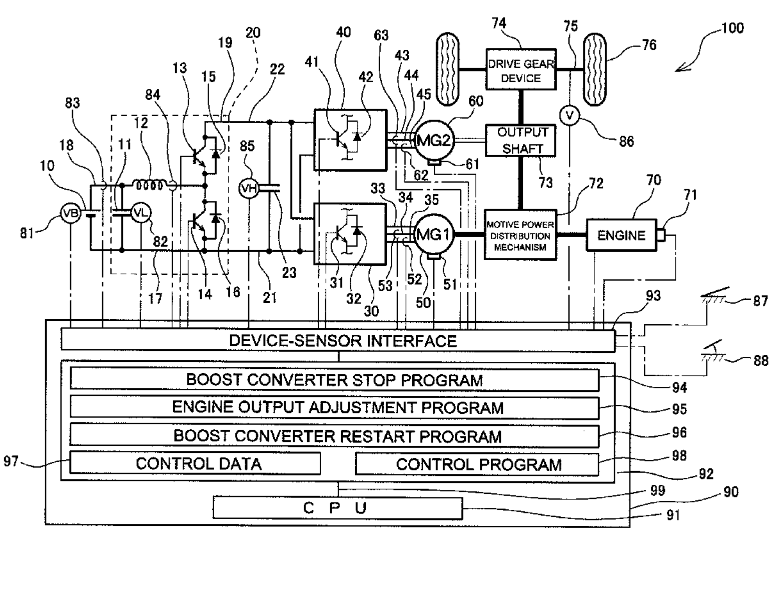
(57) **ABSTRACT**

A hybrid vehicle provided with a battery **10**, a boost converter **20**, a first inverter **30**, a second inverter **40**, a first motor generator (MG) **50** connected to the first inverter **30**, a second MG **60** connected to the second inverter **40**, an engine **70** capable of driving the first MG **50**, and a controller **90** which starts and stops the boost converter **20**. When electric power transmitted between the battery **10** and the boost converter **20** is equal to or below a predetermined threshold, the boost converter **20** is stopped. When an actual boost voltage of the boost converter **20** reaches a predetermined threshold, the first MG **50** is driven by the engine **70**. In this way, the system efficiency of a hybrid vehicle can be advantageously improved by efficiently maintaining the boost converter at a halt for a sufficiently long period.

6 Claims, 9 Drawing Sheets



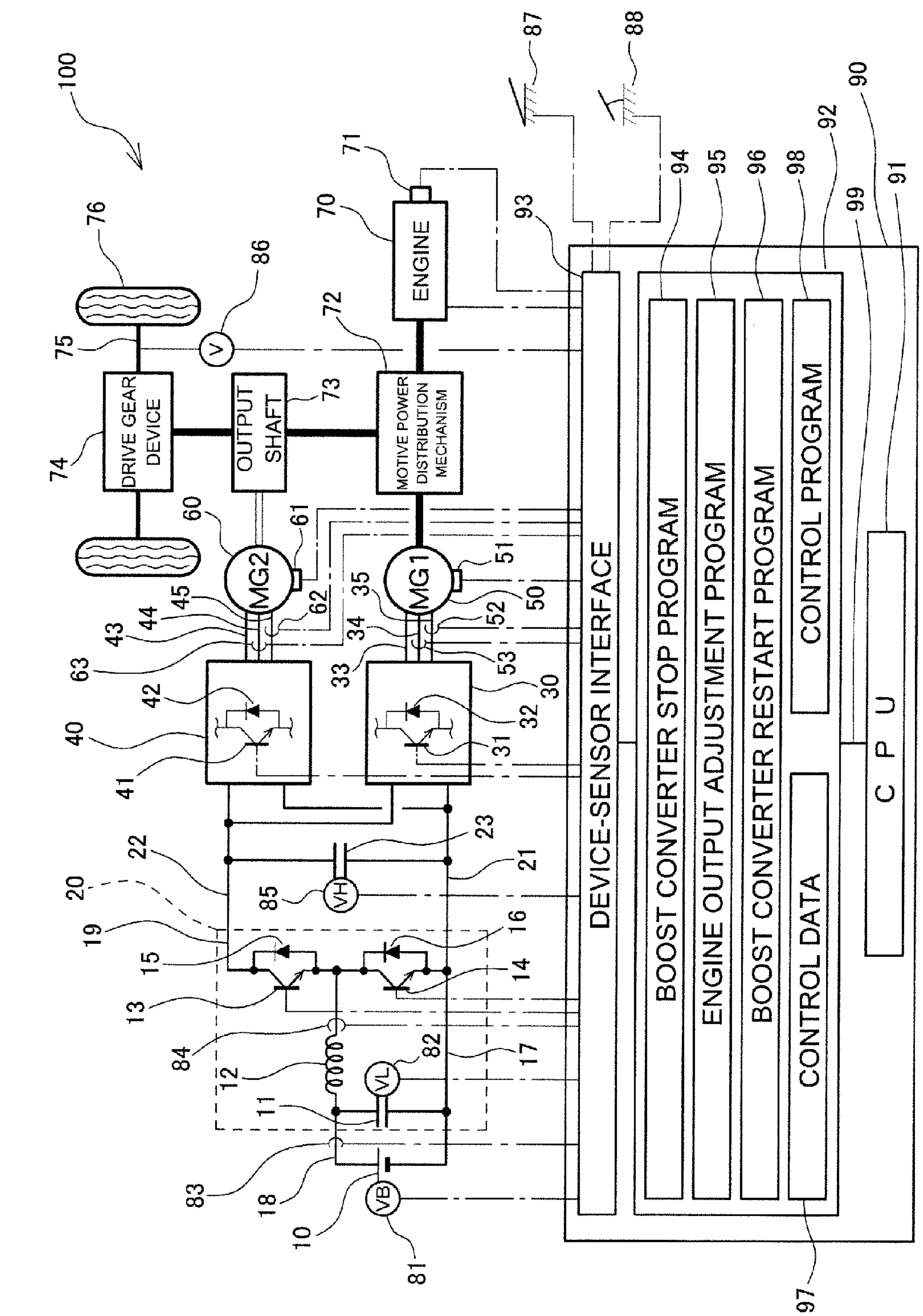

100
DRIVE GEAR DEVICE
OUTPUT SHAFT
MOTIVE POWER DISTRIBUTION MECHANISM
ENGINE
MG2
MG1
V
VH
VL
VB
DEVICE-SENSOR INTERFACE
BOOST CONVERTER STOP PROGRAM
ENGINE OUTPUT ADJUSTMENT PROGRAM
BOOST CONVERTER RESTART PROGRAM
CONTROL PROGRAM
CONTROL DATA
C P U
10
11
12
13
14
15
16
17
18
19
20
21
22
23
30
31
32
33
34
35
40
41
42
43
44
45
50
51
52
53
60
61
62
63
70
71
72
73
74
75
76
81
82
83
84
85
86
87
88
90
91
92
93
94
95
96
97
98
99

FIG. 1

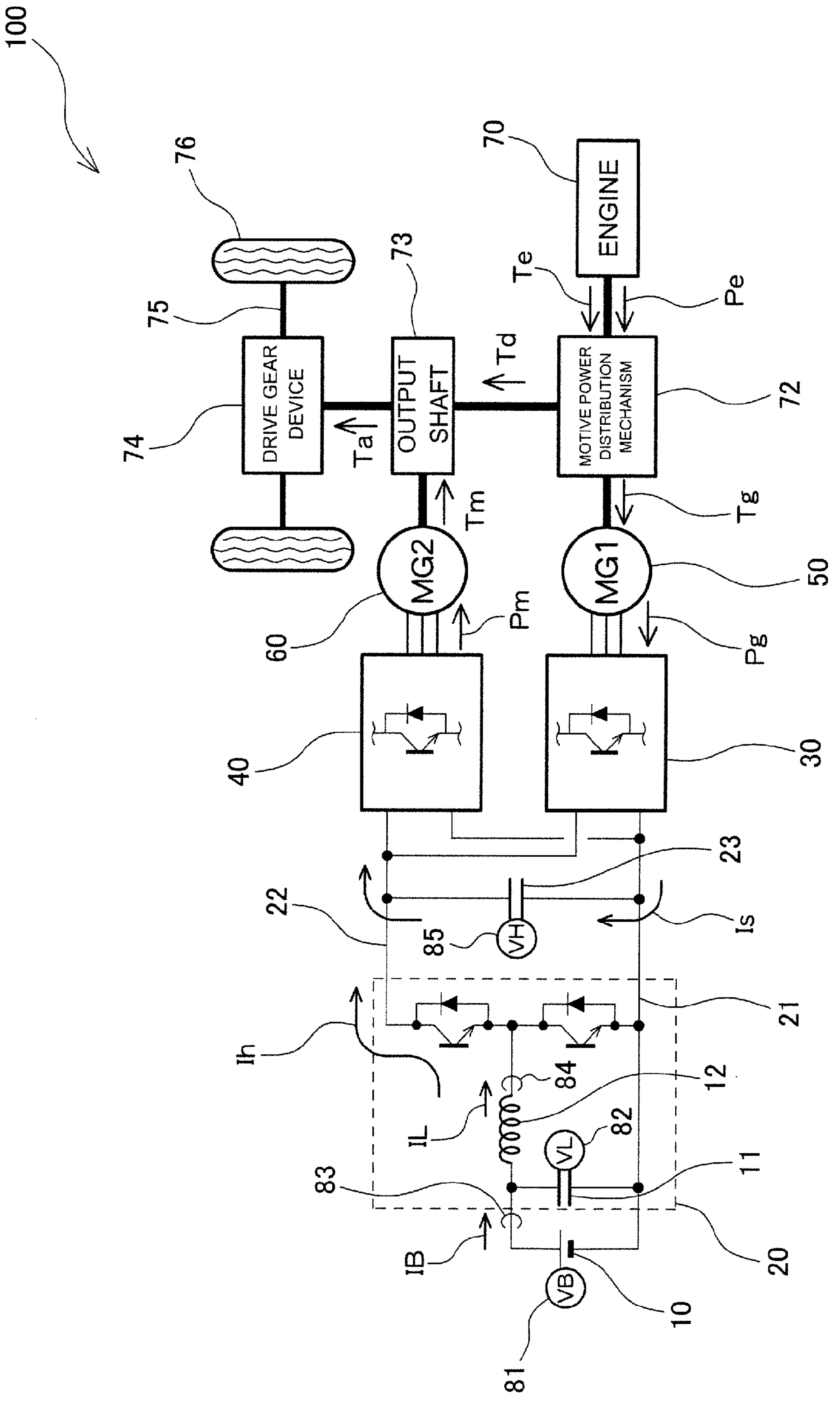

100
ENGINE
70
MOTIVE POWER DISTRIBUTION MECHANISM
72
OUTPUT SHAFT
73
DRIVE GEAR DEVICE
74
75
76
Te
Pe
Td
Ta
Tm
Tg
MG2
60
MG1
50
Pm
Pg
40
30
22
23
85
VH
Is
21
Ih
84
12
IL
82
VL
11
83
IB
20
VB
10
81

FIG. 2

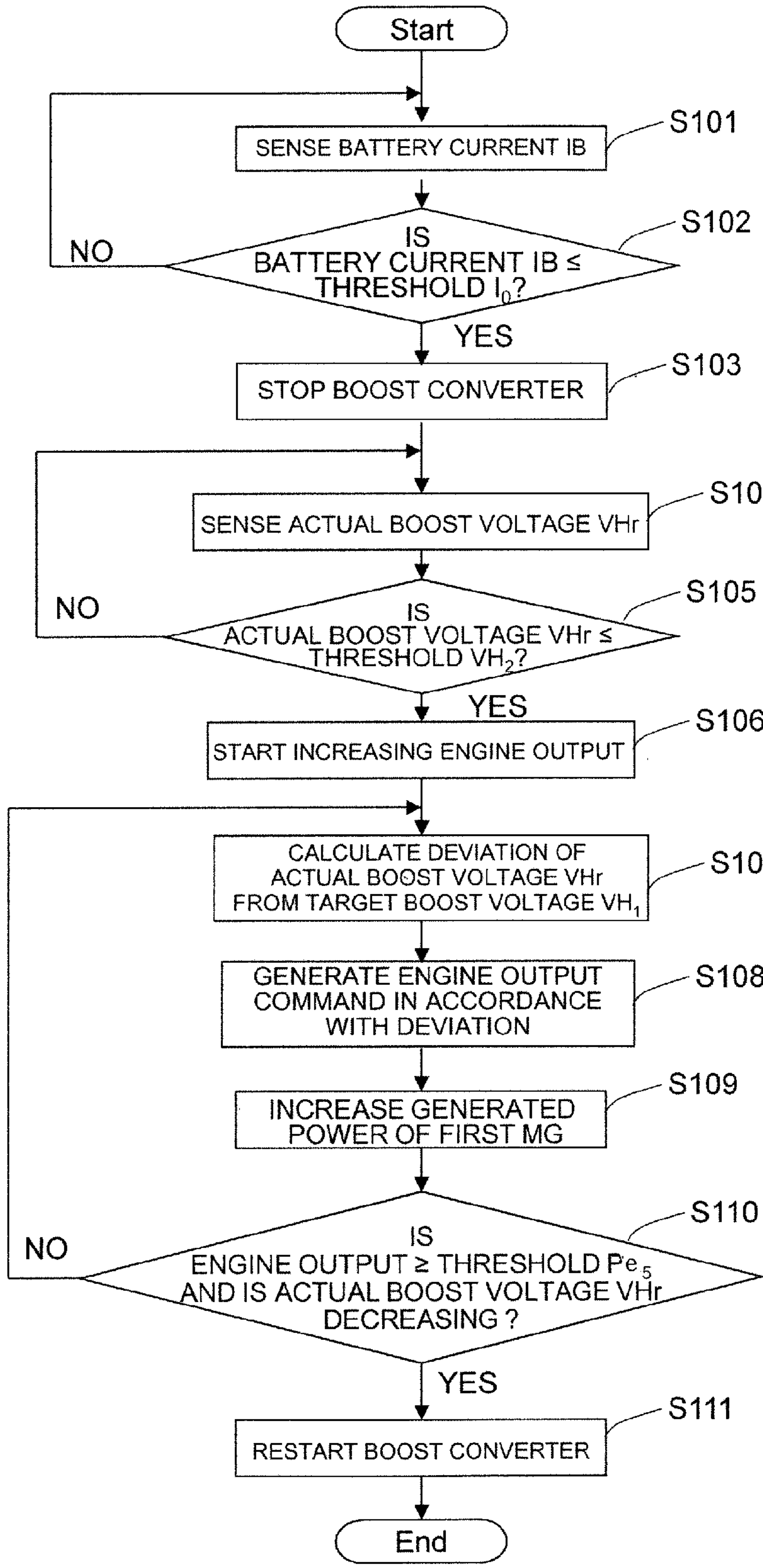

Start
SENSE BATTERY CURRENT IB
S101
IS BATTERY CURRENT IB ≤ THRESHOLD I_0?
S102
NO
YES
STOP BOOST CONVERTER
S103
SENSE ACTUAL BOOST VOLTAGE VHr
S104
IS ACTUAL BOOST VOLTAGE VHr ≤ THRESHOLD VH_2?
S105
NO
YES
START INCREASING ENGINE OUTPUT
S106
CALCULATE DEVIATION OF ACTUAL BOOST VOLTAGE VHr FROM TARGET BOOST VOLTAGE VH_1
S107
GENERATE ENGINE OUTPUT COMMAND IN ACCORDANCE WITH DEVIATION
S108
INCREASE GENERATED POWER OF FIRST MG
S109
IS ENGINE OUTPUT ≥ THRESHOLD Pe_5 AND IS ACTUAL BOOST VOLTAGE VHr DECREASING ?
S110
NO
YES
RESTART BOOST CONVERTER
S111
End

FIG. 3

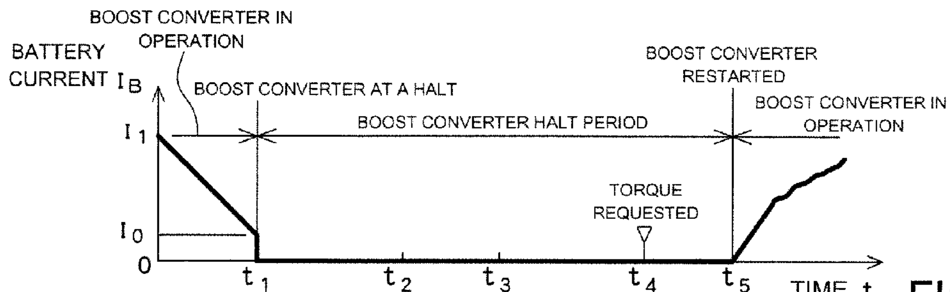


FIG. 4A

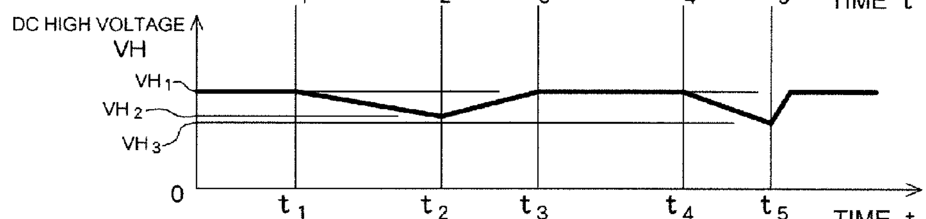


FIG. 4B

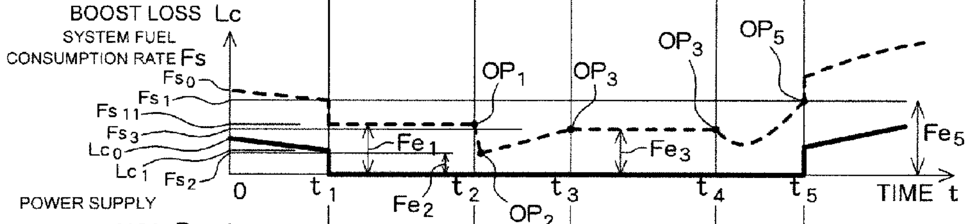


FIG. 4C

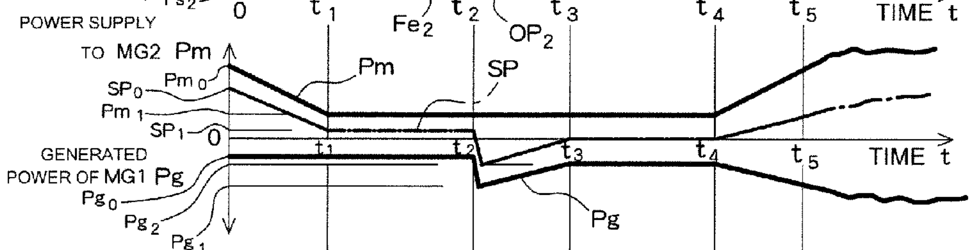


FIG. 4D

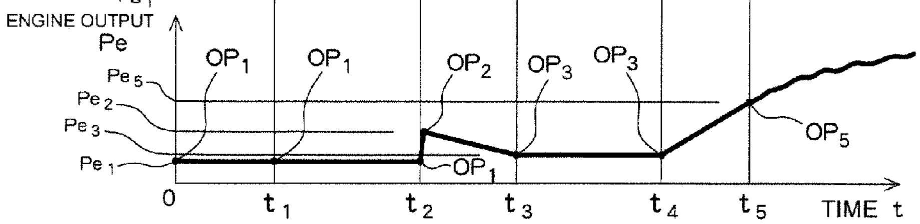


FIG. 4E

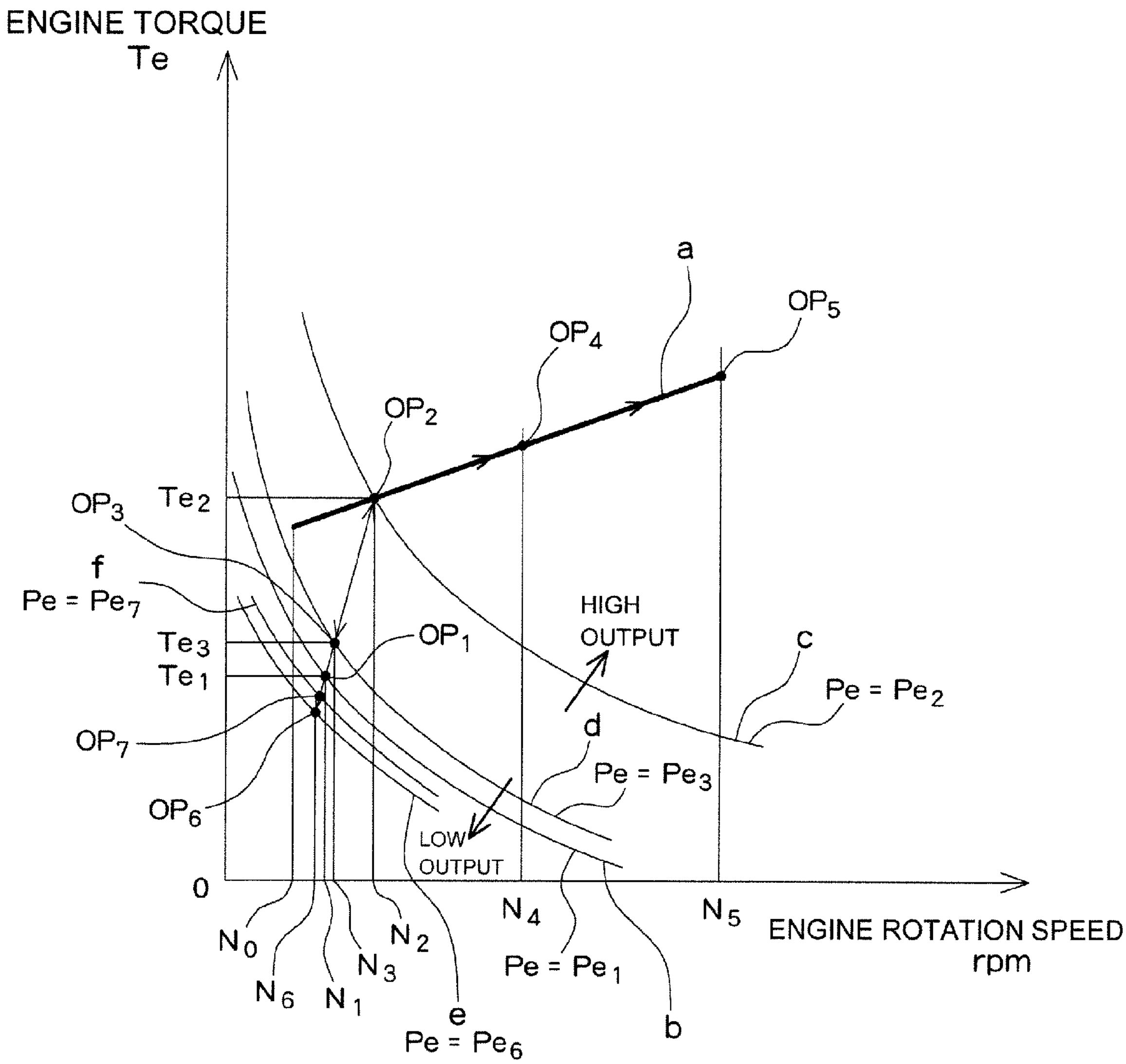

ENGINE TORQUE
Te
a
OP5
OP4
OP2
Te2
OP3
f
Pe = Pe7
Te3
Te1
OP1
HIGH
OUTPUT
c
Pe = Pe2
OP7
d
Pe = Pe3
OP6
LOW
OUTPUT
0
N0
N6
N1
N3
N2
N4
N5
ENGINE ROTATION SPEED
rpm
Pe = Pe1
e
Pe = Pe6
b

FIG. 5

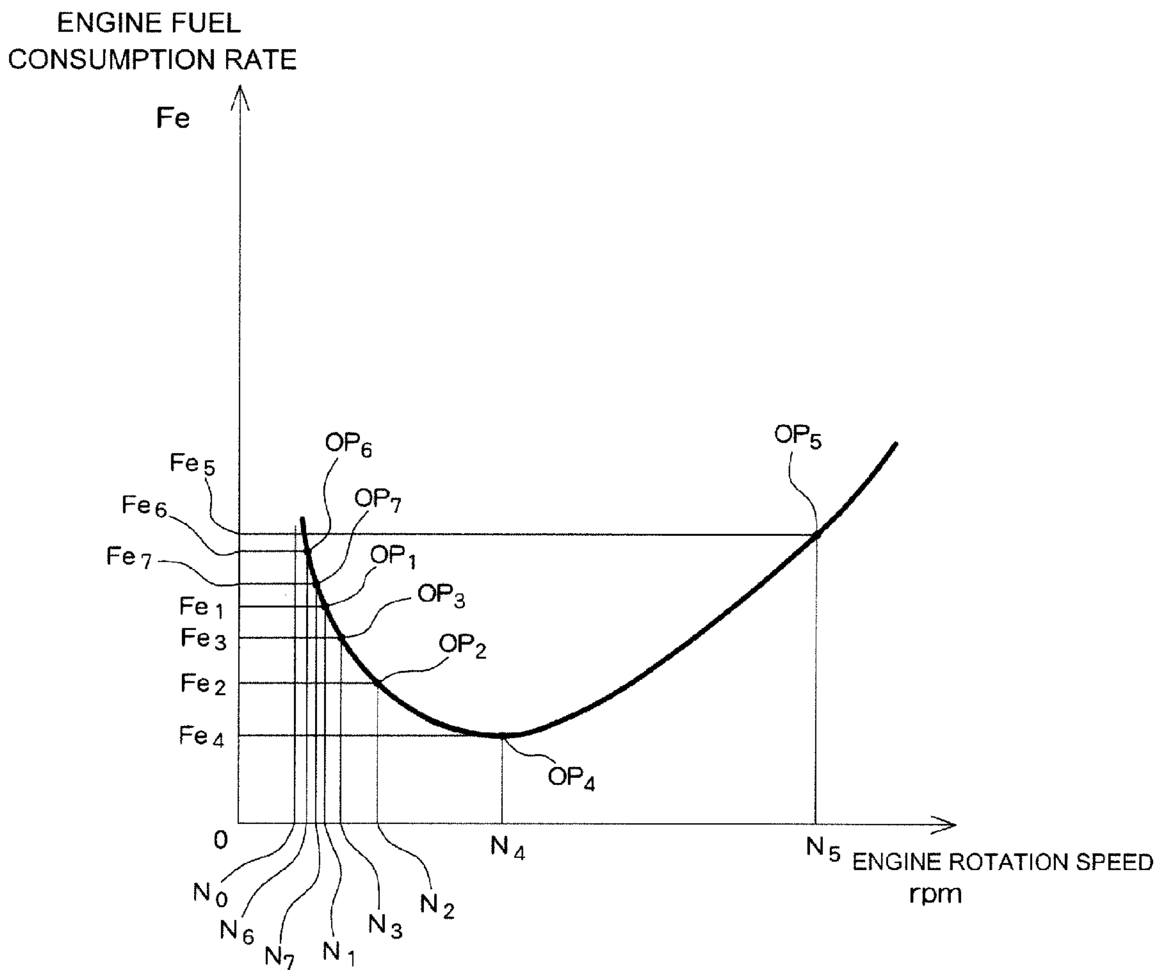

ENGINE FUEL
CONSUMPTION RATE
Fe
Fe5
Fe6
Fe7
Fe1
Fe3
Fe2
Fe4
OP6
OP7
OP1
OP3
OP2
OP4
OP5
0
N0
N6
N7
N1
N3
N2
N4
N5
ENGINE ROTATION SPEED
rpm

FIG. 6

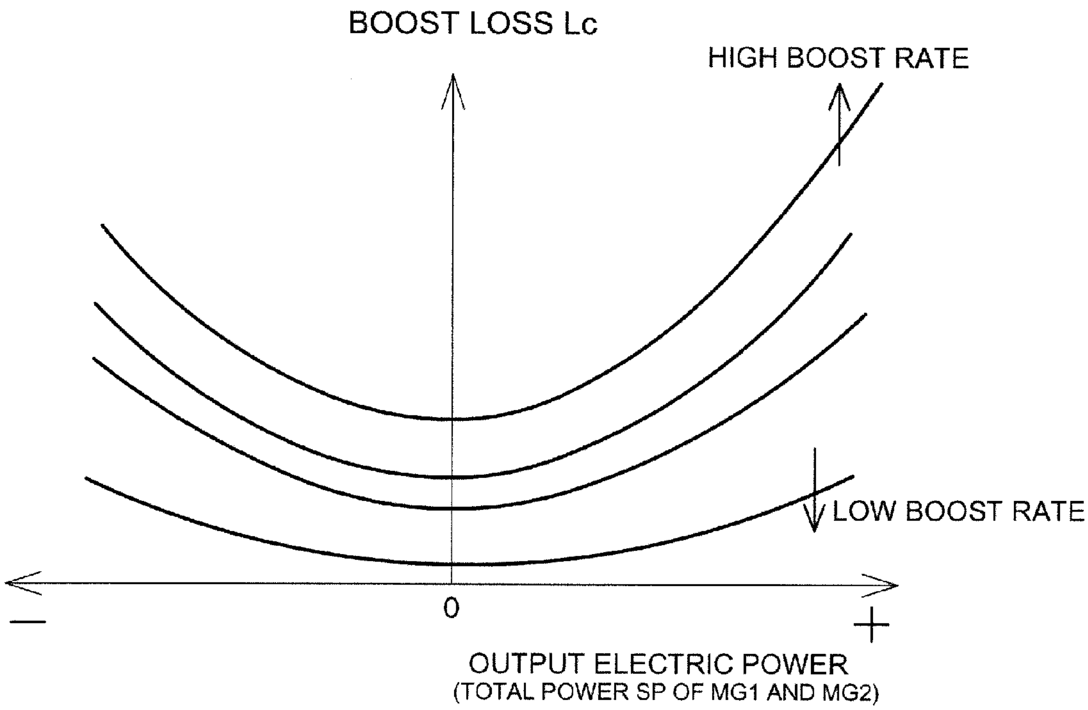

BOOST LOSS Lc
HIGH BOOST RATE
LOW BOOST RATE
0
−
+
OUTPUT ELECTRIC POWER
(TOTAL POWER SP OF MG1 AND MG2)

FIG. 7

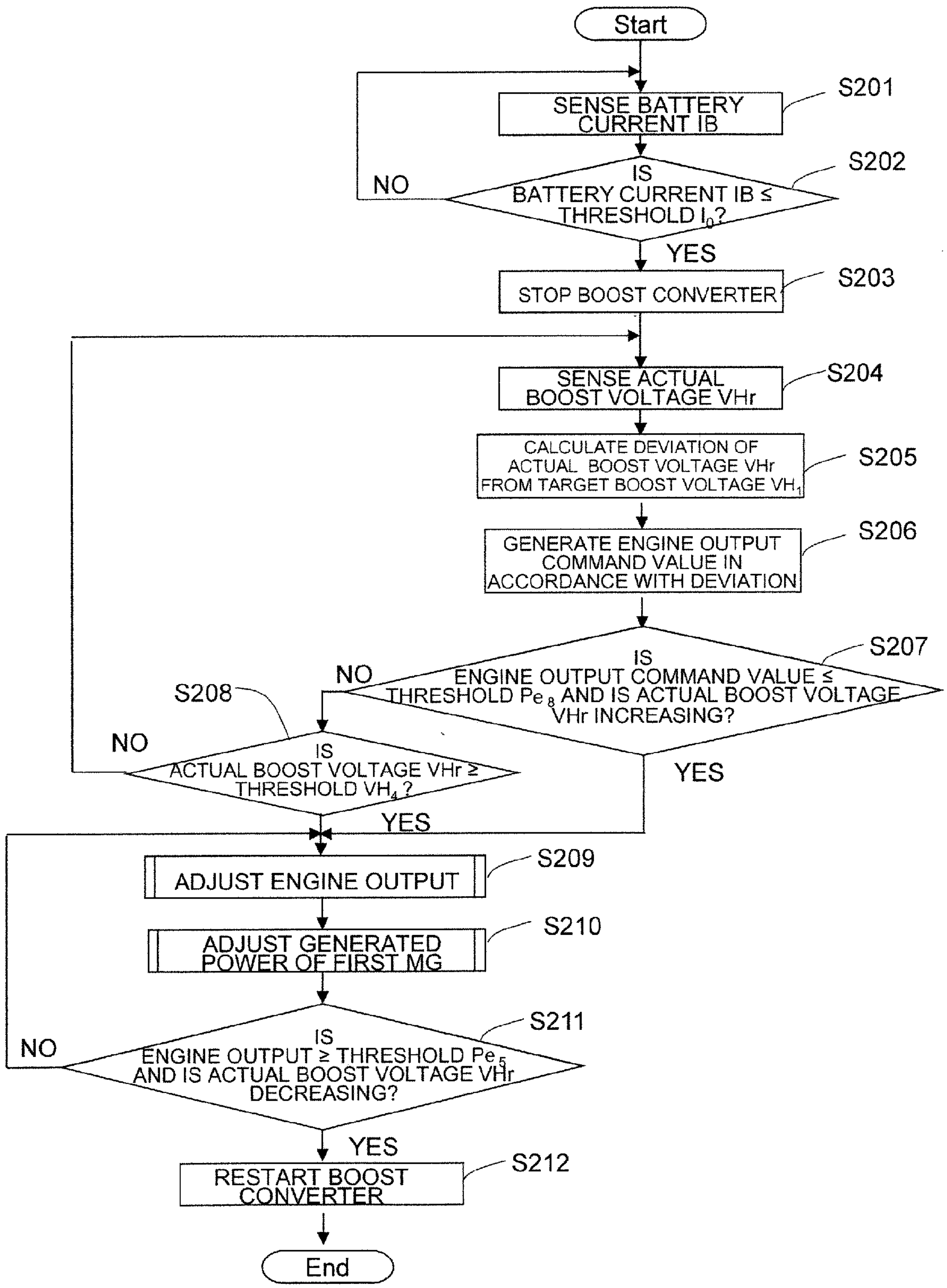

Start
SENSE BATTERY CURRENT IB
S201
IS BATTERY CURRENT IB ≤ THRESHOLD I0?
S202
NO
YES
STOP BOOST CONVERTER
S203
SENSE ACTUAL BOOST VOLTAGE VHr
S204
CALCULATE DEVIATION OF ACTUAL BOOST VOLTAGE VHr FROM TARGET BOOST VOLTAGE VH1
S205
GENERATE ENGINE OUTPUT COMMAND VALUE IN ACCORDANCE WITH DEVIATION
S206
IS ENGINE OUTPUT COMMAND VALUE ≤ THRESHOLD Pe8 AND IS ACTUAL BOOST VOLTAGE VHr INCREASING?
S207
NO
YES
S208
IS ACTUAL BOOST VOLTAGE VHr ≥ THRESHOLD VH4?
NO
YES
ADJUST ENGINE OUTPUT
S209
ADJUST GENERATED POWER OF FIRST MG
S210
IS ENGINE OUTPUT ≥ THRESHOLD Pe5 AND IS ACTUAL BOOST VOLTAGE VHr DECREASING?
S211
NO
YES
RESTART BOOST CONVERTER
S212
End

FIG. 8

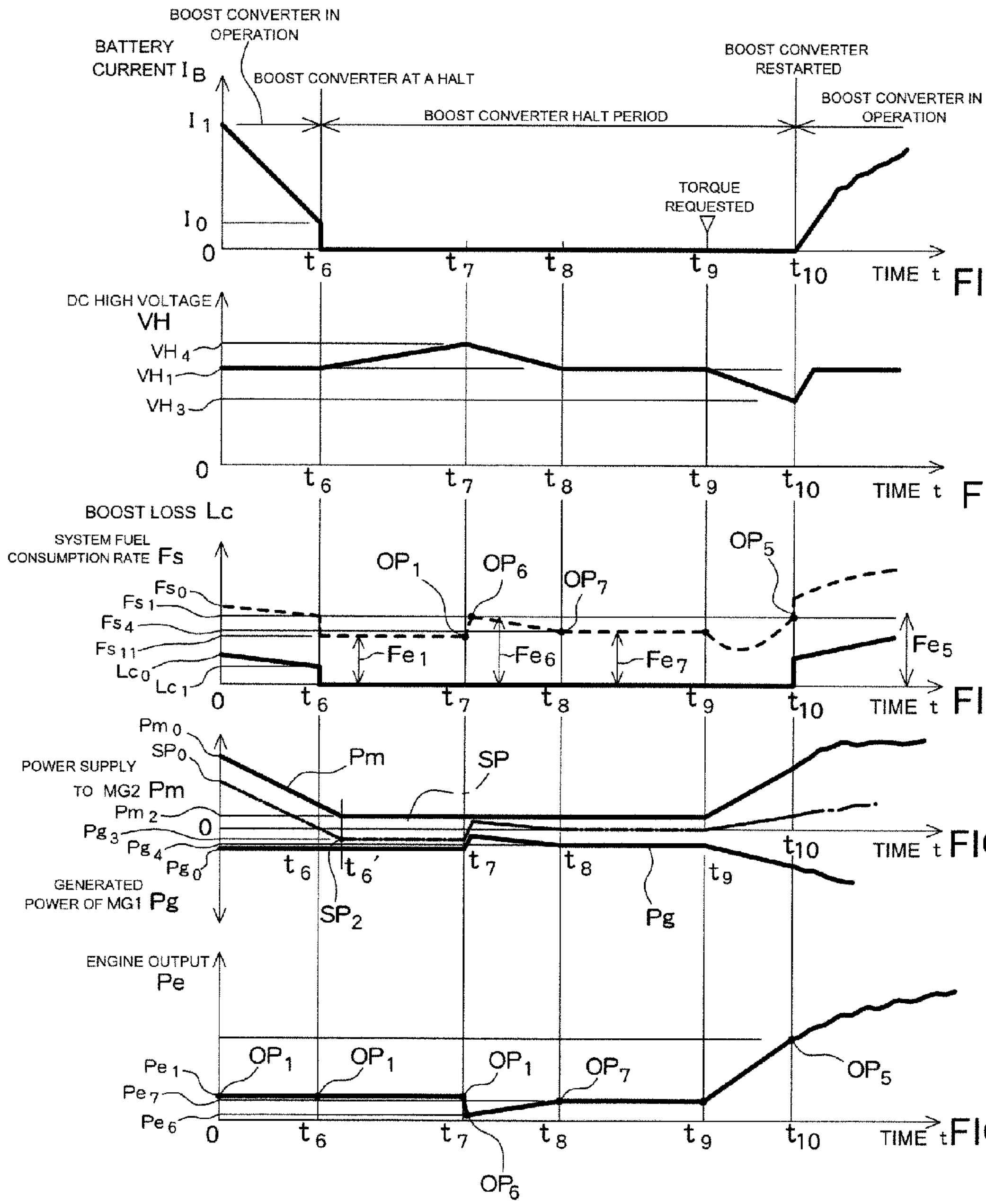


FIG. 9A

FIG. 9B

FIG. 9C

FIG. 9D

FIG. 9E

HYBRID VEHICLE HAVING BOOST CONVERTER AND CONTROL METHOD OF A HYBRID VEHICLE HAVING A BOOST CONVERTER

PRIORITY INFORMATION

This application claims priority to Japanese Patent Application No. 2014-012828 filed on Jan. 27, 2014, which is incorporated herein by reference in its entirety.

BACKGROUND

1. Technical Field

The present invention relates to a configuration of a hybrid vehicle mounted with an engine, an electric motor, and a power generator.

2. Related Art

Recently, hybrid vehicles mounted with an engine, an electric motor, and a power generator are widely used in various methods, including where a hybrid vehicle is driven by the combination of an engine output and an electric motor output depending on running conditions; and where while charging a battery by driving an electric motor with some of the engine output, a vehicle is driven by the combination of the remaining engine output and the electric motor output; and further where by driving a power generator with engine output, the generated power is used to drive an electric motor to drive a vehicle. In many cases of such a hybrid vehicle, DC low voltage of a battery is boosted to DC high voltage by a boost converter, and the boosted voltage is supplied to an electric motor or a power generator and further to each of inverters which transfer electric power to or from the electric motor or the power generator, and the electric motor is driven by converting the DC power to three-phase AC power used to drive the electric motor by each inverter, or the three-phase AC power generated by the power generator is converted to DC power.

The boost converter is used to turn ON or OFF a switching device and to boost DC low voltage of a battery by using stored energy in a reactor to output DC high voltage. Accordingly, a boost loss occurs from the ON and OFF operation of the switching device. The boost loss increases along with the increase in output electric power and boost ratio (ratio of the DC high voltage to the DC low voltage) of the boost converter, while the boost loss decreases along with the decrease of the output voltage and the boost ratio. Even when the output power of the boost converter is zero, indicating a no load state, the boost loss (switching loss) does not decrease down to zero as long as the switching device continues to be turned ON and OFF.

Ina hybrid vehicle, when the vehicle is running, for example, with the electric power generated by the power generator being balanced with the electric power consumed by the electric motor, because the electric motor can be driven by the electric power generated by the power generator without supplying the DC high voltage obtained by boosting the DC low voltage of a battery, the vehicle can continue running while maintaining the DC high voltage of the inverter at the current state. In this case, as the boost converter has no load, it may appear to be possible to improve the system efficiency of the hybrid vehicle by stopping the operation of the boost converter to reduce the boost loss (switching loss). However, because it is unlikely that the electric power consumed by the electric motor and the electric power generated by the power generator are completely balanced, if the boost converter is stopped when, for example, the electric power consumed by the electric motor is slightly larger than the electric power generated by the power generator, the DC high voltage of the inverter will gradually decrease. Therefore, methods are proposed to maintain the DC high voltage of the inverter at a target voltage by stopping the operation of the boost converter and by correcting the output torque of the electric motor so as to maintain the output power of the power generator at a constant level to minimize the deviation of the DC high voltage of the inverter from the target voltage when the electric power generated by the power generator and the electric power consumed by the electric motor are substantially balanced (refer to, for example, JP 2011-15603 A).

SUMMARY

In the conventional art described in JP 2011-15603 A, because the output electric power of a power generator cannot be changed, when the electric power output to the power generator is increased in response to a request while the boost converter is at a halt, it is impossible to compensate the increased electric power output to the power generator. Accordingly, the DC high voltage of the inverter decreases. Because it is impossible to maintain the predetermined DC high voltage, it is required to immediately restart the boost converter in response to a receipt of the request to increase the electric power output to the power generator. In other words, in the conventional art described in JP 2011-15603 A, because it is impossible to meet both of the requests to increase the electric power output to the power generator and to stop the boost converter at the same time, the time to maintain the boost converter at a halt becomes shorter. Therefore, there has been a problem that the system efficiency of hybrid vehicles cannot be sufficiently improved.

The present invention has an object to advantageously improve the system efficiency of a hybrid vehicle by maintaining a boost converter at a halt for a sufficiently long period.

A hybrid vehicle according to the present invention is characterized by including a battery; a boost converter connected to the battery; a first inverter connected to the boost converter; a second inverter connected to the boost converter and the first inverter; a power generator connected to the first inverter; an electric motor connected to the second inverter; an engine capable of driving the power generator; and a controller which starts and stops the boost converter, wherein the controller includes a boost converter stop unit which stops the boost converter when electric power transferred between the battery and the boost converter is equal to or below a predetermined threshold, and drives the power generator by the engine when an actual boost voltage of the boost converter reaches a predetermined threshold.

In a hybrid vehicle according to the present invention, it is preferable that the controller includes an engine output adjustment unit which changes an engine output in accordance with a deviation of the actual boost voltage of the boost converter from a target boost voltage.

In a hybrid vehicle according to the present invention, it is preferable that the controller includes a boost converter restart unit which restarts the boost converter when the actual boost voltage does not increase even by increasing the engine output.

A hybrid vehicle according to the present invention is characterized by including a battery; a boost converter connected to the battery; a first inverter connected to the boost converter; a second inverter connected to the boost converter and the first inverter; a power generator connected to the first inverter; an electric motor connected to the second inverter;

an engine capable of driving the power generator; and a controller which includes a CPU and starts and stops the boost converter, wherein the controller executes, using the CPU, a boost converter stop program which stops the boost converter when electric power transferred between the battery and the boost converter is equal to or below a predetermined threshold, and drives the power generator by the engine when an actual boost voltage of the boost converter reaches a predetermined threshold.

A control method of a hybrid vehicle according to the present invention is characterized in that the hybrid vehicle includes a battery; a boost converter connected to the battery; a first inverter connected to the boost converter; a second inverter connected to the boost converter and the first inverter; a power generator connected to the first inverter; and an electric motor connected to the second inverter; an engine capable of driving the power generator, wherein the boost converter is stopped when electric power transferred between the battery and the boost converter is equal to or below a predetermined threshold, and the power generator is driven by the engine when an actual boost voltage of the boost converter reaches a predetermined threshold.

The present invention has an advantage that the system efficiency of a hybrid vehicle can be efficiently improved by maintaining a boost converter at a halt for a sufficiently long period.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a system diagram showing a configuration of a hybrid vehicle according to an embodiment of the present invention.

FIG. **2** is an illustrative diagram showing flows of motive power, electric power, and electric current of a hybrid vehicle according to an embodiment of the present invention.

FIG. **3** is a flowchart showing operations of a hybrid vehicle according to an embodiment of the present invention.

FIG. **4**A is a graph showing changes in electric current of a battery over time during the operation shown in FIG. **3**.

FIG. **4**B is a graph showing changes in DC high voltage over time during the operation shown in FIG. **3**.

FIG. **4**C is a graph showing changes in a boost loss and a system fuel consumption rate over time during the operation shown in FIG. **3**.

FIG. **4**D is a graph showing changes in electric power supply to a second motor generator and generated power of a first motor generator over time during the operation shown in FIG. **3**.

FIG. **4**E is a graph showing changes in an engine output over time during the operation shown in FIG. **3**.

FIG. **5** is a graph showing changes in operation points of an engine of a hybrid vehicle according to an embodiment of the present invention.

FIG. **6** is a graph showing changes in an engine fuel consumption rate at the operation points of the engine shown in FIG. **5**.

FIG. **7** is graph showing loss characteristics of a boost converter mounted on a hybrid vehicle according to an embodiment of the present invention.

FIG. **8** is a flowchart showing other operations of a hybrid vehicle according to an embodiment of the present invention.

FIG. **9**A is a graph showing changes in electric current of a battery over time during the operation shown in FIG. **8**.

FIG. **9**B is a graph showing changes in DC high voltage over time during the operation shown in FIG. **8**.

FIG. **9**C is a graph showing changes in a boost loss and a system fuel consumption rate over time during the operation shown in FIG. **8**.

FIG. **9**D is a graph showing changes in electric power supply to a second motor generator and generated power of a first motor generator over time during the operation shown in FIG. **8**.

FIG. **9**E is a graph showing changes in engine output over time during the operation shown in FIG. **8**.

DETAILED DESCRIPTION

Embodiments of the present invention are described below with reference to the attached drawings. As shown in FIG. **1**, a hybrid vehicle **100** according an embodiment of the present invention is provided with a battery **10** which is a rechargeable and dischargeable secondary battery, a boost converter **20** connected to the battery **10**, a first inverter **30** connected to the boost converter **20**, a second inverter **40** connected to the boost converter **20** and the first inverter **30**, a first motor generator **50** which is a power generator connected to the first inverter **30**, a second motor generator **60** which is a power generator connected to the second inverter **40**, an engine **70** capable of driving the first motor generator **50**, and a controller **90** which controls the engine **70**, the boost converter **20**, and the first and the second inverters **30**, **40**.

As shown in FIG. **1**, the hybrid vehicle **100** is further provided with a motive power distribution mechanism **72** which distributes the output torque of the engine **70** between an output shaft **73** connected to the second motor generator **60** and the first motor generator **50**, a drive gear device **74** connected to the output shaft **73**, an axle **75** connected to the drive gear device **74**, and wheels **76** connected to the axle **75**. The first and second motor generators **50**, **60** and the engine **70** are respectively provided with resolvers **51**, **61**, **71**, each of which senses a rotation angle or rotation speed of a rotor or crankshaft. Further, the axle **75** is provided with a vehicle speed sensor **86** which senses the vehicle speed of the hybrid vehicle **100** by sensing the number of rotations of the axle.

The boost converter **20** is provided with a negative-side electrical path **17** connected to the negative side of the battery **10**, a low-voltage electrical path **18** connected to the positive side of the battery **10**, and a high-voltage electrical path **19** at a positive-side output end of the boost converter **20**. The boost converter **20** is provided with an upper arm switching device **13** positioned between the low-voltage electrical path **18** and the high-voltage electrical path **19**, a lower arm switching device **14** positioned between the negative-side electrical path **17** and the low-voltage electrical path **18**, a reactor **12** positioned in series in the low-voltage electrical path **18**, and a reactor current sensor **84** which senses reactor current IL flowing through the reactor **12**, a filter capacitor **11** positioned between the low-voltage electrical path **18** and the negative-side electrical path **17**, and a low voltage sensor **82** which senses DC low voltage VL at both ends of the filter capacitor **11**. Further, the switching devices **13**, **14** are respectively provided with diodes **15**, **16** which are connected in anti-parallel. The boost converter **20** stores electrical energy from the battery **10** in the reactor **12** by turning ON the lower arm switching device **14** and turning OFF the upper arm switching device **13**. Then, the boost converter **20** boosts the voltage by using the stored electrical energy in the reactor **12** by turning OFF the lower arm switching device **14** and turning ON the upper arm switching device **13** to supply boosted DC high voltage VH to the high-voltage electrical path **19**.

The battery **10** is mounted with a battery voltage sensor **81** which senses a battery voltage VB. A battery current sensor

83 is also attached to the low-voltage electrical path 18 between the battery 10 and the boost converter 20 for sensing a battery current IB flowing between the battery 10 and the boost converter 20.

The first inverter 30 and the second inverter 40 are provided with a common high-voltage electrical path 22 connected to the high-voltage electrical path 19 of the boost converter 20 and a common negative-side electrical path 21 connected to the negative-side electrical path 17 of the boost converter 20. A smoothing capacitor 23 which smoothens the DC current supplied from the boost converter 20 is connected between the high-voltage electrical path 22 and the negative-side electrical path 21. The DC high-voltage VH which is boost voltage supplied to the inverters 30, 40 is sensed by a high-voltage sensor 85 which senses voltage at both ends of the smoothing capacitor 23. Therefore, the DC high-voltage VH sensed by the high-voltage sensor 85 is an actual boost voltage (actual boost voltage VHr). Accordingly, in the present embodiment, the actual boost voltage VHr supplied to each of the first and the second inverters 30, 40 is the same voltage. The first inverter 30 converts DC power supplied from the boost converter 20 to the first three-phase AC power, and supplies the first three-phase AC power to the first motor generator 50. The first inverter 30 further converts the first three-phase AC power generated by the first motor generator 50 to DC power, and charges the DC power to the battery 10 via the boost converter 20, or supplies the converted DC power to the second inverter 40. The second inverter 40 converts the DC power supplied from the boost converter 20 to the second three-phase AC power, and supplies the second three-phase AC power to the second motor generator 60. The second inverter 40 further converts the second three-phase AC power generated by the second motor generator 60 to DC power, and charges the DC power to the battery 10 via the boost converter 20, or supplies the converted DC power to the first inverter 30.

The first inverter 30 internally includes two switching devices, each at an upper arm and a lower arm of each of U, V, W phases, and thus six switching devices 31 are provided in total. Each switching device 31 includes a diode 32 connected in anti-parallel (in FIG. 1, one of the six switching devices and one of the diodes are shown, while the other switching devices and the diodes are omitted). Output lines 33, 34, 35 which output electric current in respective phases (U, V, or W) are connected between the upper arm switching device and the lower arm switching device of each of the U, V, and W phases of the first inverter 30. Each of the output lines 33, 34, 35 is connected to an input terminal of each of the U, V, and W phases of the first motor generator 50. Further, in the present embodiment, the V-phase and W-phase output lines 34, 35 respectively include current sensors 53, 52, which respectively sense the electric current of the V-phase and W-phase output lines 34, 35. It should be noted that although no current sensor is attached to the U-phase output line 33, the U-phase current value can be obtained based on the V-phase and W-phase current values because, in three-phase AC current, the sum of the U-phase, V-phase, and W-phase electric current is zero.

The configurations of the second inverter 40 (including switching device 41, diode 42, and output lines 43, 44, 45) and the electric sensors 62, 63 are respectively identical to those of the first inverter 30 and the current sensors 52, 53. The hybrid vehicle 100 is further provided with an accelerator pedal depression amount sensor 87 and a brake pedal depression amount sensor 88 which respectively sense a depression amount of an accelerator pedal and a brake pedal.

As shown in FIG. 1, the controller 90 is a computer including a CPU 91 which performs operations and information processing, a storage unit 92, and a device-sensor interface 93, all of which are connected via a data bus 99. The storage unit 92 stores control data 97, a control program 98, a boost converter stop program 94 (described further below, and also referred to as "boost converter stop unit"), an engine output adjustment program 95 (also referred to as "engine output adjustment unit"), and a boost converter restart program 96 (also referred to as "boost converter restart unit"). The above described switching devices 13, 14 of the boost converter 20 and the switching devices 31, 41 of the first and the second inverters 30, 40 are connected to the controller 90 via the device-sensor interface 93 and configured to be operated in response to commands from the controller 90. Further, outputs from each sensor (the battery voltage sensor 81, the low voltage sensor 82, the high-voltage sensor 85, the battery current sensor 83, the reactor current sensor 84, the current sensors 52, 53, 62, 63, the resolvers 51, 61, 71, the vehicle speed sensor 86, the accelerator pedal depression amount sensor 87, and the brake pedal depression amount sensor 88) are supplied to the controller 90 via the device-sensor interface 93.

Basic operations of the hybrid vehicle 100 are briefly described below with reference to FIG. 2 before describing operations of the hybrid vehicle 100 configured as described above when the boost converter is at a halt. Although the hybrid vehicle 100 is provided with various drive modes, a drive mode in which the hybrid vehicle 100 is driven by outputs from the engine 70 and the second motor generator 60 is described below.

The engine 70 outputs an engine output Pe and an engine torque Te. The engine torque Te is distributed by the motive power distribution mechanism 72 to a first torque Tg which is used to drive the first motor generator 50 and a directly-to-engine torque Td which is used to drive the wheels 76 via the output shaft 73 and the drive gear device 74. As the motive power distribution mechanism 72, a planetary gear system or the like may be used. Serving as a power generator, the first motor generator 50 is driven by the first torque Tg from the motive power distribution mechanism 72 and outputs generated power Pg which is three-phase AC power to the first inverter 30. The first inverter 30 converts the supplied AC generated power Pg to DC power as DC high power and outputs the converted power to the high-voltage electrical path 22 and the negative-side electrical path 21. The output DC current Is is supplied to the second inverter 40 via the smoothing capacitor 23.

The battery current IB of battery voltage VB supplied from the battery 10 is charged into a filter capacitor 11 of the boost converter 20 such that the voltage at both ends of the filter capacitor 11 becomes DC low voltage VL. Therefore, when the battery 10 and the boost converter 20 are connected with the filter capacitor 11 which has been charged, the battery voltage VB becomes equal to the DC low voltage VL. As described above, the boost converter 20 stores electric energy from the battery 10 in the reactor 12 by turning the lower arm switching device 14 ON and the upper arm switching device 13 OFF. Then, the boost converter 20 boosts the voltage with the electric energy stored in the reactor 12 by turning the lower arm switching device 14 OFF and the upper arm switching device 13 ON, and outputs boosted DC high voltage VH to the high-voltage electrical path 19. At this time, the electric power of (battery voltage VB×battery current IB) or (DC low voltage VL×reactor current IL) is supplied to the boost converter 20 from the battery 10. The boost converter 20 outputs this supplied electric power as electric power of (DC high voltage VH×average current Ih). The controller 90 controls the ON/OFF duty of each of the switching devices **13**, **14** to adjust the DC high voltage VH to be the target boost voltage VH_1.

The DC current Ih of the DC high voltage VH output from the boost converter **20** is merged with the DC current Is of the DC high voltage VH output from the first inverter **30** and then supplied to the second inverter **40**. The second inverter **40** converts the DC power of the supplied DC high voltage VH and the DC current (Is+Ih) to three-phase AC power supply Pm, and supplies the converted power to the second motor generator **60** which serves as a motor. The second motor generator **60** is driven by the power supply Pm and supplies motor torque Tm to the output shaft **73**. The above described directly-to-engine torque Td and the motor torque Tm are supplied to the output shaft **73**. The total torque Ta of the directly-to-engine torque Td and the motor torque Tm are transmitted to the drive gear device **74**. The wheels **76** are driven by the total torque Ta of the directly-to-engine torque Td and the motor torque Tm, respectively output from the engine **70** and the second motor generator **60**. It should be noted that in the description below, it is assumed that the electric power towards each of the motor generators **50**, **60** is positive, while the electric power from each of the motor generators **50**, **60** to each of the inverters **30**, **40** is negative. Therefore, the generated power Pg of the first motor generator **50** is negative and the power supply Pm supplied to the second motor generator **60** is positive.

When the motive power required for the hybrid vehicle **100** is low, the DC power of the DC high voltage VH and the DC current Is output from the first inverter **30** are not supplied to the second inverter **40** but stepped-down by the boost converter **20** and charged to the battery **10**. Further, during braking the hybrid vehicle **100**, the second motor generator **60** also serves as a power generator, and the generated AC power (negative) is converted by the second inverter **40** to DC power and charged to the battery **10**.

Next, with reference to FIGS. **3** to **7**, operations of a hybrid vehicle **100** according to the present invention are described below, including operations to stop the boost converter **20**, adjusting operations of the engine output Pe with the boost converter **20** at a halt when the absolute value of the power supply Pm (positive) supplied to the second motor generator **60** is larger than the absolute value of the generated power Pg (negative) generated by the first motor generator **50**, and restarting operations of the boost converter **20**. It should be noted that OP_1 to OP_3 and OP_5 in FIGS. **4**C and **4**E respectively correspond to the operation points OP_1 to OP_3, and OP_5 of the engine **70** shown in FIGS. **5** and **6**.

At time zero (initial state) shown in FIGS. **4**A to **4**E, the boost converter **20** is in operation, and the actual boost voltage VHr which is the DC high voltage VH sensed by the high-voltage sensor **85** is equal to the target boost voltage VH_1. The engine **70** is operated at an operation point OP' with the engine output $Pe=Pe_1$ (refer to FIG. **5**). As shown in FIG. **4**D, the first motor generator **50** is driven as a power generator by the engine **70**. The generated power Pg is Pg_0 (negative). As described above with reference to FIG. **2**, the generated power Pg_0 is converted by the first inverter **30** to DC power of the target boost voltage VH_1 and the DC current Is ($VH_1 \times Is$) and supplied to the second inverter **40**. Further, at time zero (initial state), the battery current IB output from the battery **10** is I_1. Because the voltage of the battery **10** is the battery voltage VB, the DC power of (battery voltage $VB \times I_1$) is supplied from the battery **10** to the boost converter **20**. The total DC power of the DC power from the first inverter **30** ($VH_1 \times Is$) and the DC power from the battery **10** (battery voltage $VB \times I_1$) is supplied to the second inverter **40**, which converts the total DC power to the power supply Pm (positive) supplied to the second motor generator **60** and outputs the converted power. In other words, in order to compensate the difference between the absolute value of the power supply Pm (positive) supplied to the second motor generator **60** and the absolute value of the generated power Pg (negative) of the first motor generator **50**, the DC power of (battery voltage $VB \times I_1$) is supplied from the battery **10** to the boost converter **20**. Accordingly, the total power SP of the generated power Pg (negative) of the first motor generator **50** and the power supply Pm (positive) supplied to the second motor generator **60** is Pg_0 (negative)+Pm_0 (positive)=SP_0 (positive). As shown in FIG. **4**D, because the absolute value of Pm_0>the absolute value of Pg_0 at time zero, SP_0 is positive.

Further, as shown by the solid line in FIG. **4**C, the boost loss (switching loss) Lc of the boost converter **20** at time zero is Lc_0. Because the engine **70** is operated at an operation point OP_1, the engine fuel consumption rate Fe is Fe_1 as shown in FIG. **6**. In the present embodiment, the system fuel consumption rate Fs (reciprocal of the system efficiency) of the hybrid vehicle **100** is defined as the sum of the engine fuel consumption rate Fe shown in FIG. **6** and a boost fuel consumption rate Fc which is obtained by converting the boost loss Lc shown in FIG. **7** to the system fuel consumption rate. Accordingly, the following equation can be defined:

System fuel consumption rate Fs=Engine fuel consumption rate Fe+Boost fuel consumption rate Fc

Therefore, as shown by the broken line in FIG. **4**C, the system fuel consumption rate Fs_0 at time zero is the sum of the engine fuel consumption rate Fe_1 at the operation point OP_1 of the engine **70** and the boost fuel consumption rate Fc_0 which is obtained by converting the boost loss Lc_0 to the fuel consumption rate ($Fs_0=Fe_1+Fc_0$).

The controller **90** performs the boost converter stop program **94** (boost converter stop unit) shown in FIG. **1**. First, as shown in step S**101** in FIG. **3**, the controller **90** obtains the battery current IB by the battery current sensor **83**. As described above, at time zero shown in FIGS. **4**A to **4**E, in order to compensate the difference between the absolute value of the power supply Pm (positive) supplied to the second motor generator **60** and the absolute value of the generated power Pg (negative) generated by the first motor generator **50**, the DC power of (battery voltage $VB \times I_1$) is supplied from the battery **10** to the boost converter **20**.

As shown in step S**102** in FIG. **3**, the controller **90** compares the battery current IB sensed by the battery current sensor **83** and a threshold I_0. The threshold I_0 is such a current value that because the battery current IB is very low, the DC power output from the boost converter **20** (battery voltage $VB \times I_0$) can be assumed to be about zero. As shown in step S**102** in FIG. **3**, when the battery current IB is not less than or equal to the threshold I_0, the controller **90** returns to step S**101** in FIG. **3** to continue monitoring of the battery IB.

When the output torque command of the second motor generator **60** is low as shown in a period from time zero to time T_1 in FIG. **4**D, the power supply Pm supplied to the second motor generator **60** gradually decreases from Pm_0 at time zero. Along with this decrease, the battery current IB also gradually decreases from I_1 at time zero. Because the engine **70** is operated at the operation point OP_1 shown in FIG. **5** during this period, the engine output Pe is constant at Pe_1 and the generated power of the first motor generator **50** driven by the engine **70** is also constant at Pg_0 as shown in FIGS. **4**D, **4**E. Therefore, the total power SP of the generated power Pg (negative) of the first motor generator **50** and the power supply Pm (positive) supplied to the second motor generator **60** also gradually decreases from SP_0 at time zero. When the total power SP of the generated power Pg (negative) of the first motor generator **50** and the power supply Pm (positive) supplied to the second motor generator **60** decreases down to near zero, the boost loss Lc of the boost converter **20** also decreases as shown in FIG. **7**. Accordingly, as shown by the solid line in FIG. **4**C, the boost loss Lc decreases from Lc_0 to Lc_1 during a period from time zero to time t_1. In this way, the system fuel consumption rate Fs also gradually decreases from ($Fs_0=Fe_1+Fc_0$) at time zero to ($Fs_1=Fe_1+Fc_1$). It should be noted here that the Fc_1 indicates a boost fuel consumption rate which is obtained by converting the boost loss Lc_1 to the fuel consumption rate.

When the power supply Pm supplied to the second motor generator **60** decreases down to Pm' at time t_1 as shown in FIG. **4**D, the battery current IB decreases down to zero as shown in FIG. **4**A. Then, the controller **90** determines in step S**102** in FIG. **3** that the battery current IB is less than or equal to the threshold I_0, and issues a command to stop the boost converter **20** as shown in step S**103** in FIG. **3**. In response to this command, the upper arm switching device **13** and the lower arm switching device **14** of the boost converter **20** are turned OFF to disconnect the connection between the boost converter **20** and each of the first and the second inverters **30**, **40**, and the boost converter stop program **94** (boost converter stop unit) is exited.

Because the connection between the boost converter **20** and each of the first and the second inverters is disconnected when the boost converter **20** is stopped at time t_1 in FIG. **4**A, no electric current flows from the battery **10** to the second inverter **40**. Accordingly, the battery current IB decreases down to zero and the DC current supplied from the battery **10** to the second inverter **40** also decreases down to zero. The power supply Pm supplied to the second motor generator **60** is the total power of the generated power Pg of the first motor generator **50** and the discharged power Pc of the smoothing capacitor **23**. Further, because the switching devices **13**, **14** of the boost converter **20** are maintained to be OFF, the boost loss Lc caused by switching decreases from Lc_1 to zero as shown by the solid line in FIG. **4**C. Accordingly, as shown by the broken line in FIG. **4**C, the system fuel consumption rate Fs is reduced from the Fs_1 ($Fs_1=Fe_1+Fc_1$) to Fs_{11} which is lowered for the amount of the boost fuel consumption rate Fc_1 obtained by converting the boost loss Lc_1 ($Fs_{11}=Fs_1-Fc_1$). Accordingly, because the system fuel consumption rate Fs is reduced for the amount of the boost fuel consumption rate Fc_1, the system efficiency is improved. Because the system fuel consumption rate Fs becomes equal to the engine fuel consumption rate Fe when the boost converter **20** is stopped as shown in FIG. **4**C, the equation is defined as $Fs_{11}=Fe_1$. Even when the boost converter **20** is stopped at time t_1, the actual boost voltage VHr which is the voltage at both ends of the smoothing capacitor **23** sensed by the high-voltage sensor **85** is maintained at the target boost voltage VH_1, which is the boost voltage before the boost converter **20** is stopped, by using electric charge stored in the smoothing capacitor **23**.

Because the engine **70** continues to operate at the operation point OP_1 at which the engine output Pe is maintained at Pe_1 as shown in FIG. **4**E even when the boost converter **20** is stopped at time T_1, the generated power Pg of the first motor generator **50** is maintained at Pg_0, which is the same as at time zero. Further, as shown in FIG. **4**D, the output torque of the second motor generator **60** is substantially constant, and the power supply Pm (positive) supplied to the second motor generator **60** is maintained at Pm_1, which is the same as at time t_1 when the boost converter **20** was stopped. It should be noted here that because the absolute value of the power supply Pm_1 supplied to the second motor generator **60** at time t_1 is larger than the absolute value of the generated power Pg_0 (negative) of the first motor generator **50**, the total power SP of both power is SP_1(=Pm_1+Pg_0) which is slightly in positive.

As described above, because, when the boost converter **20** is at a halt, the absolute value of the power supply Pm' supplied to the second motor generator **60** is larger than the absolute value of the generated power Pg_0 (negative) of the first motor generator **50**, the smoothing capacitor **23** discharges the discharge power Pc to compensate the amount of the total power SP_1. Accordingly, as shown in FIG. **4**B, the actual boost voltage VHr gradually decreases from the target boost voltage VH_1 after time T_1.

After exiting the boost converter stop program **94** shown in FIG. **1**, the controller **90** starts executing the engine output adjustment program **95** (engine output adjustment unit) shown in FIG. **1** at time t_1 shown in FIG. **4**E. The controller **90** senses the actual boost voltage VHr at both ends of the smoothing capacitor **23** using the high-voltage sensor **85**, as shown in step S**104** in FIG. **3**. Then, the controller **90** determines whether or not the actual boost voltage VHr is less than or equal to the first threshold voltage VH_2, as shown in step S**105** in FIG. **3**. When the actual boost voltage VHr is not less than or equal to the first threshold voltage VH_2, the controller **90** returns to step S**104** in FIG. **3** to continue monitoring of the actual boost voltage VHr. As shown in FIG. **4**B, when the actual boost voltage VHr is equal to or below the first threshold voltage VH_2 at time T_2, the controller **90** outputs a command to increase the engine output Pe, as shown in step S**106** in FIG. **3**.

As shown in step S**107** in FIG. **3**, the controller **90** calculates a deviation of the actual boost voltage VHr sensed by the high-voltage sensor **85** from the target boost voltage VH_1. Because the actual boost voltage VHr sensed by the high-voltage sensor **85** is equal to the first threshold voltage VH_2 at time t_2, the deviation is obtained by (VH_1-VH_2). As shown in step S**108** in FIG. **3**, the controller **90** calculates a suitable increase of the engine output Pe in accordance with the obtained deviation (VH_1-VH_2) and generates an output command to the engine. For example, the increase of the engine output Pe may be set at a value in proportion to the deviation (VH_1-VH_2). Then, as shown in step S**109** in FIG. **3**, the controller **90** increases both of the engine output Pe and the generated power Pg of the first motor generator **50**.

With reference to FIGS. **5** and **6**, relationships among the rotation speed, engine torque Te, engine output Pe (kW), and engine fuel consumption rate Fe of the engine **70** are described below. The lines b, c, d, e, and f in FIG. **5** are curves showing relationships between the rotation speed and engine torque Te of the engine **70** when the engine output Pe is maintained at a constant level at Pe_1, Pe_2, Pe_3, Pe_6, or Pe_7 ($Pe_6<Pe_7<Pe_1<Pe_3<Pe_2$). As shown in FIG. **5**, the curves b to f depart farther from the origin along with the increase of the engine output Pe. Further, the line a in FIG. **5** shows an optimal control curve in which the fuel consumption rate of the engine **70** (fuel consumption rate with the vehicle in the hybrid running mode) is minimum. In a normal operation, the rotation speed and the engine torque Te of the engine **70** are controlled along the line a. The rotation speed N_0 in FIG. **5** is the idling rotation speed of the engine **70**. In a normal operation, the engine **70** is operated at a rotation speed equal to or over this rotation speed No. In FIG. **5**, OP_1 to OP_7 are operation points of the engine **70**. FIG. **6** shows changes in the engine fuel consumption rate Fe of the engine **70** from the operation points OP_1 to OP_7.

At time t_2 in FIG. **4**E, the engine **70** is operated at the operation point OP_1 with the engine output Pe at Pe_1 and the engine rotation speed at N_1. As indicated by the wide departure from the optimal control curve a, at the operation point OP_1, the efficiency of the engine **70** is low and the engine consumption rate Fe is high at Fe_1 as shown in FIG. **6**. As described above, at time T_2, the deviation of the actual boost voltage VHr sensed by the high-voltage sensor **85** from the target boost voltage VH_1 is (VH_1-VH_2). The controller **90** sets the command value of the engine output Pe at Pe_2 based on this deviation (VH_1-VH_2). Accordingly, the controller **90** increases the engine output Pe from Pe_1 at the operation point OP_1 at $time_1$ to Pe_2, as shown in FIG. **4**E. The operation point of the engine **70** moves to the operation point OP_2 with the rotation speed N_2 and engine torque Te_2. As shown in FIG. **5**, because the operation point OP_2 is on the operation control curve a, the operation point OP_2 is more efficient than the operation point OP_1 that has departed from the optimal control curve a such that, as shown in FIG. **6**, the engine fuel consumption rate Fe is Fe_2 which is below Fe_1. Accordingly, because, as shown by the broken line in FIG. **4**C, the system fuel consumption rate Fs decreases from Fs_{11} ($=Fe_1$) at which the boost converter **20** was stopped at time t_1 to Fs_2 ($=Fe_2$), the system fuel consumption rate Fs of the hybrid vehicle **100** is reduced for the amount of $(Fs_{11}-Fs_2)=(Fe_1-Fe_2)$. In other words, the system fuel consumption rate Fs decreases for the amount equal to the decrease of the engine fuel consumption rate Fe caused by the increase of the output of the engine **70**. The system efficiency of the hybrid vehicle **100** increases for the amount equal to this decrease. Further, because the engine output is increased to Pe_2, the generated power Pg of the first motor generator **50** is increased from Pg_0 at time t_2 to Pg_2. In this way, the smoothing capacitor **23** is charged (the discharge power Pc of the smoothing capacitor **23** becomes negative) such that the voltage at both ends of the smoothing capacitor **23** increases. Accordingly, as shown in FIG. **4**B, the actual boost voltage VHr sensed by the high-voltage sensor **85** gradually increases after time t_2.

Because the engine output Pe_2 is below the threshold Pe_5 of the engine output Pe as shown in FIG. **4**E (the threshold Pe_5 of the engine output Pe is described further below), in step S**110** in FIG. **3**, the controller **90** determines that the engine output Pe is not over the threshold Pas and the actual boost voltage VHr is not decreasing, and returns to S**107** in FIG. **3** to calculate a deviation of the actual boost voltage VHr sensed by the high-voltage sensor **85** from the target boost voltage VH_1.

As shown in FIG. 4B, because the actual boost voltage VHr sensed by the high-voltage sensor **85** increases after time t_2, the deviation of the actual boost voltage VHr sensed by the high-voltage sensor **85** from the target boost voltage VH_1 gradually decreases in comparison to the deviation (VH_1-VH_2) at time t_2. Accordingly, the controller **90** reflects the deviation in the increase of the engine output Pe such that the engine output Pe is controlled to be decreased from Pe_2 at time T_2 along with the decrease in the deviation.

As shown in FIGS. **4**E and **4**B, during a period from time t_2 to time t_3, the actual boost voltage VHr sensed by the high-voltage sensor **85** gradually increases towards the target boost voltage VH_1, while the engine output Pe gradually decreases. The operation point of the engine **70** moves in a direction departing from the optimal control curve a from the operation point OP_2 at time t_2 towards the operation point OP_3 at which the engine output Pe is at Pe_3. Because, in this way, the engine fuel consumption rate Fe increases from Fe_2 to Fe_3 as shown in FIG. **6**, the system fuel consumption rate Fs of the hybrid vehicle **100** also increases from Fs_2 ($=Fe_2$) immediately after time T_2 for the amount equal to $(Fs_3-Fs_2)=(Fe_3-Fe_2)$ in addition to Fs_3 ($=Fe_3$) at time t_3. Therefore, the system fuel consumption rate Fs increases, while the system efficiency of the hybrid vehicle **100** decreases for the amount equal to this increase.

As shown in FIGS. **4**B, **4**D, and **4**E, when the engine output Pe is at Pe_3 at t_3, the generated power of the first motor generator **50** becomes Pg_2 such that the absolute value of the Pg_2 becomes equal to the absolute value of the power supply supplied to the second motor generator **60**. In other words, the generated power Pg of the first motor generator **50** and the power supply Pm supplied to the second motor generator **60** are in a balanced state. Accordingly, the discharge power Pc of the smoothing capacitor **23** becomes zero, while the actual boost voltage VHr sensed by the high-voltage sensor **85** is maintained at the target boost voltage VH_1 after reaching the target boost voltage VH_1.

When the driver steps on the accelerator pedal of the hybrid vehicle **100** at time t_4 in FIGS. **4**A to **4**E, the accelerator pedal depression amount sensed by the accelerator pedal depression amount sensor **87** increases. Therefore, the controller **90** determines that a request to increase the drive torque has been received and issues commands to increase the motor torque Tm of the second motor generator **60** and the engine torque Te of the engine **70**. In response to these commands, the power supply Pm supplied to the second motor generator **60** and the engine output Pe are increased after t_4, as shown in FIG. **4**D. When the accelerator pedal depression amount is not large, the boost converter **20** can be maintained at a halt because it is possible to maintain the generated power Pg of the first motor generator **50** and the supplied power Pm supplied to the second motor generator **60** in a balanced state by increasing the engine torque Te to increase the generated power Pg of the first motor generator **50**.

In contrast, when the accelerator pedal depression amount is large, the controller **90** determines that a request to significantly increase the torque has been received and shifts to an operation mode in which some of the engine torque Te is applied to a directly-to-engine torque Td and the torque Ta supplied to the drive gear device **74** is increased. Accordingly, in the engine output Pe, the amount of output used for the power generation of the first motor generator **50** gradually decreases. Therefore, the amount of generated power Pg of the first motor generator **50** decreases below the power supply Pm supplied to the second motor generator **60**. Because this shortfall is supplemented by the discharged power Pc discharged by the smoothing capacitor **23**, the actual boost voltage VHr sensed by the high-voltage sensor **85** gradually decreases. In this way, the deviation of the actual boost voltage VHr sensed by the high-voltage sensor **85** from the target boost voltage VH_1 gradually increases, causing the engine output Pe to be increased.

When the operation point of the engine **70** moves from the operation point OP_3 at which the engine output is at Pea at time t**4** in the direction to increase the engine output Pe, the controller **90** moves the operation point of the engine **70** to the operation point OP_2 on the optimal control curve a. Then, the controller **90** moves the operation point from OP_2 to OP_4, and to OP_5 along with the optimal control curve a shown in FIG. **5**. As shown in FIG. **6**, the engine fuel consumption rate Fe becomes minimum when the rotation speed of the engine **70** is N_4. After that, the engine fuel consummation rate Fe increases along with an increase in the engine output Pe along the optimal control curve a. Accordingly, as shown by the broken line in FIG. **4**C, although the system fuel consumption rate Fs temporarily decreases due to a decrease in the engine fuel consumption rate Fe immediately after the start of the increase of the engine output Pe at time t_4, the engine fuel consumption rate Fs gradually increases thereafter, caused by an increase in the engine consumption rate Fe which is increased by continuously increasing the engine output Pe. Then, at time t_5, the operation point reaches at OP_5 where the engine fuel consumption rate Fe becomes Fe_5 which is equal to the system fuel consumption rate Fs_1 before the boost converter **20** was stopped at time t_1. Accordingly, when the engine output Pe is set equal to or over Pe_5, the system fuel consumption rate Fs of the hybrid vehicle **100** increases over the system fuel consumption rate Fs_1 before the boost converter **20** was stopped. Therefore, when the boost converter **20** is maintained at a halt, the system efficiency of the hybrid vehicle **100** is reduced compared to when the boost converter **20** is in operation. As described above, the threshold Pe_5 in the engine output adjustment program **95** indicates an engine output Pe_5 at which a system efficiency deterioration starts due to an increase of the engine fuel consumption rate Fe.

The controller **90** increases the engine output Pe in accordance with the decrease in the actual boost voltage VHr sensed by the high-voltage sensor **85** by executing steps S**107** to S**110** shown in FIG. **3** during a period from time T_4 to time t_5 at which the engine output Pe reaches the threshold Pe_5. When the engine output Pe reaches the threshold Pe_5, the controller **90** determines in step S**110** shown in FIG. **3** that the engine output Pe is equal to or over the threshold and that the actual boost voltage VHr is not increasing but decreasing, and exits the engine output adjustment program **95** (engine output adjustment unit). As shown in step S**111** in FIG. **3**, the controller **90** executes the boost converter restart program **96** to restart the boost converter **20**.

When restarted, the boost converter **20** boosts the DC low voltage VL from the battery **10** to DC high voltage VH and supplies the boosted voltage to the high-voltage electrical path **22** such that a normal operation described above with reference to FIG. **2** is performed with the smoothing capacitor **23** being charged and the actual boost voltage VHr being increased to the target boost voltage VH_1.

As described above, in the hybrid vehicle **100** according to the present embodiment, it becomes possible to maintain, for a long period, the system fuel consumption rate Fs of the hybrid vehicle **100** below a level applied before the boost converter **20** is stopped by increasing the generated power Pg of the first motor generator **50**, which is a power generator, by using the engine **70**, and thus the system efficiency of the hybrid vehicle **100** can be efficiently improved. Further, in the present embodiment, because the engine output Pe is temporarily increased after the boost converter **20** is stopped, and the DC high voltage VH is maintained at a constant level by decreasing the engine output Pe in accordance with the deviation of the actual boost voltage VHr sensed by the high-voltage sensor **85** from the target boost voltage VH_1 to balance between the generated power Pg of the first motor generator **50** and the power supply Pm supplied to the second motor generator **60**, the DC high voltage VH can be maintained at a constant level with the minimum required engine output Pe. Therefore, the loss of the system of the hybrid vehicle **100** as a whole can be lowered to the minimum. Further, when the actual boost voltage VHr continues to decrease, the boost converter **20** is restarted to perform a normal operation so as to secure the drivability by restricting shortage of the output from the second motor generator **60**.

Although, in the above described embodiment, the boost converter **20** is restarted only when the engine output Pe is set equal to or over the threshold with the actual boost voltage VHr decreasing, the boost converter **20** may be restarted by exiting the engine output adjustment program **95** and executing the boost converter restart program **96** (boost converter restart unit) even when the engine output Pe has not reached the threshold Pe_5 if the actual boost voltage VHr sensed by the high-voltage sensor **85** does not increase by increasing the engine output Pe and the actual boost voltage is maintained at or below the second threshold VH_3. The second threshold voltage VH_3 may be equal to or different from the first threshold voltage VH_2.

Next, with reference to FIGS. **8**, and **9**A to **9**E, operations of the hybrid vehicle **100** according to an embodiment of the present invention are described concerning stopping the boost converter **20**, adjusting the engine output Pe with the boost converter **20** at a halt when the absolute value of the power supply Pm (positive) supplied to the second motor generator **60** decreases below the absolute value of the generated power Pg (negative) generated by the first motor generator **50** immediately after the boost converter **20** is stopped, and restarting the boost converter **20**. It should be noted that the operation points OP_1, and OP_5 to OP_5 in FIGS. **9**C and **9**E correspond to the operation points OP_1, and OP_5 to OP_7 of the engine **70** shown in FIGS. **5** and **6**. The operations identical to those described above with reference to FIGS. **3**, and **4**A to **4**E are described simply below.

As shown in FIGS. **9**A to **9**E, the hybrid vehicle **100** operates at time zero with the battery current $IB=I_1$, the DC high voltage VH (actual boost voltage VHr)$=VH_1$, the boost loss $Lc=Lc_0$, the engine output $Pe=Pe_1$, the system fuel consumption rate $Fs=Fs_0$, the engine fuel consumption rate $Fe=Fe_1$, the power supply Pm to the second motor generator **60**$=Pm_0$, and the generated power Pg of the first motor generator **50**$=Pg_0$, similarly to as shown in FIGS. **4**A to **4**E.

Similarly to steps S**101** to S**103** in FIG. **3**, the controller **90** executes the boost converter stop program **94** (boost converter stop unit) shown in FIG. **1**, and monitors the battery current IB by sensing the battery current IB with the high-voltage sensor **85** as shown in steps S**201** and S**202** in FIG. **8**. When the battery current IB decreases down to or below the threshold I_0, the controller **90** stops the boost converter **20** as shown in step S**203** in FIG. **8** and exits the boost converter stop program **94** (boost converter stop unit).

As shown in FIG. **9**D, even when the boost converter **20** is stopped at time T_6, the power supply Pm supplied to the second motor generator **60** continues to decrease until the power supply Pm is equal to Pm_2 at time t_6' immediately after time t_6. Therefore, at time t_6', the absolute value (positive) of the power supply Pm_2 supplied to the second motor generator **60** is below the absolute value of the generated power Pg_0 (negative) of the first motor generator **50**. Accordingly, the total power SP of both of the power is $SP_2(=Pm_2+Pg_0)$ which is slightly negative. Therefore, as shown in FIG. **9**B, charging to the smoothing capacitor **23** is started from time t_6 at which the boost converter **20** is stopped such that the actual boost voltage VHr at both ends of the smoothing capacitor **23** is started to increase from the target boost voltage VH_1.

After exiting the boost converter stop program **94** shown in FIG. **1**, the controller **90** starts executing the engine output adjustment program **95** (engine output adjustment unit) shown in FIG. **1** at time t_6 shown in FIG. **9**E. As shown in step S**204** in FIG. **8**, the controller **90** senses the actual boost voltage VHr at both ends of the smoothing capacitor **23**.

As shown in step S**205** in FIG. **8**, the controller **90** calculates a deviation of the actual boost voltage VHr sensed by the high-voltage sensor **85** from the target boost voltage VH_1. Then, as shown in step S**206** in FIG. **8**, the controller **90** calculates a sufficient amount of engine output Pe to be increased in accordance with the obtained deviation and generates an output command value to the engine. Because the actual boost voltage VHr sensed by the high-voltage sensor **85** at time t_6 is at the target boost voltage VH_1, the deviation becomes zero and the engine output command value to be output becomes the engine output Pe_6 at time t_6. Then, the controller **90** determines whether the engine output command value is equal to or below the threshold value Pe_8 and the actual boost voltage VHr is increasing.

The threshold Pe_8 is an engine output Pe such that the engine fuel consumption rate Fe becomes equal to the system fuel consumption rate Fs_1 applied before the boost converter **20** is stopped, and if the engine output Pe decreases to or below the Pe_8, the system fuel consumption rate Fs of the hybrid vehicle **100** increases over the system fuel consumption rate Fs_1 which is the same as before the boost converter **20** is stopped. Accordingly, when the engine output Pe decreases to or below the Pe_8 while maintaining the boost converter **20** at a halt, the system efficiency of the hybrid vehicle **100** is lowered compared to a case where the boost converter **20** is in operation. As described above, the threshold Pe_8 in the engine output adjustment program **95** is an engine output Pe at which the system efficiency starts to be lowered due to a decrease in the engine fuel consumption rate Fe.

When the engine output Pe is maintained at Pe_1 which is the same as at time t_6, the actual voltage VHr at both ends of the smoothing capacitor **23** gradually increases from the target boost voltage VH_1 as shown in the period between time t_6 to time t_7 in FIG. **9**B such that the deviation (negative) of the actual boost voltage VHr from the target boost voltage VH_1 also gradually increases. In this way, the engine output command value calculated by the controller **90** in step S**206** in FIG. **8** gradually decreases. When the engine command value becomes equal to or below the threshold Pe_8, the controller **90** skips the step S**208** shown in FIG. **8** and proceeds to step S**209** in which the controller **90** adjusts the engine output while no longer increasing the actual boost voltage VHr. As shown in step S**210** in FIG. **8**, the controller **90** adjusts the generated power Pg of the first motor generator **50**. The engine output Pe and the generated power Pg of the first motor generator **50** are adjusted by changing the engine output Pe and the generated power Pg of the first motor generator **50** in accordance with the deviation of the actual boost voltage VHr from the target boost voltage VH_1 as shown in steps S**107** to S**109** in FIG. **3**. After time t_6 in FIG. **9**B, because the actual boost voltage VHr is over the target boost voltage VH_1, the deviation is negative. Accordingly, the controller **90** decreases the engine output Pe and the generated power Pg of the first motor generator **50**.

Further, the controller **90** proceeds to step S**208** in FIG. **8** when the engine command value is not equal to or below the threshold Pee, and determines whether the actual boost voltage VHr is equal to or over the third threshold voltage VH_4. When the actual boost voltage VHr is not equal to or over the third threshold voltage VH_4, the controller **90** monitors the actual boost voltage VHr by repeating the steps S**204** to S**208**. When the actual boost voltage VHr becomes equal to or over the third threshold voltage VH_4, the controller **90** proceeds to steps S**209** and S**210** to decrease the engine output Pe and the generated power Pg of the first motor generator **50**.

When the actual boost voltage VHr reaches the third threshold voltage VH_4 at time t_7, the deviation of the actual boost voltage VHr sensed by the high-voltage sensor **85** from the target boost voltage VH_1 is (VH_1-VH_4) (in negative). Based on this deviation (VH_1-VH_4), the controller **90** decreases the command value of the engine output Pe from Pe_1 at the operation point OP_1 at time t_6 towards Pe_6 at the operation point OP_6. In this way, as shown by the broken line in FIG. **9**C, the engine fuel consumption rate Fs increases from Fe_1 at time t_7 towards Fe_6. Accordingly, the system fuel consumption rate Fs of the hybrid vehicle **100** also increases from Fs_{11} ($=Fe_1$) at time t_7 towards Fe_6.

As shown in the period from immediately after time t_7 shown in FIG. **9**E to time t_8, the actual boost voltage VHr decreases by reducing the engine output Pe. When the deviation of the actual boost voltage VHr from the target boost voltage VH_1 becomes closer to zero, the controller **90** repeats the steps S**209** to S**211** in FIG. **8** to increase the engine output Pe to Pe_7 in accordance with the deviation until the deviation becomes zero. At this time, the operation point of the engine **70** moves from the operation point OP_6 at time t_7 to the operation point OP_7. Because the engine fuel consumption rate Fe decreases from Fe_6 immediately after time t_7 to Fe_7 at time t_8, the system fuel consumption rate Fs of the hybrid vehicle **100** decreases for the amount of (Fe_7-Fe_6). In other words, the system fuel consumption rate is improved for this amount.

As shown in FIGS. **9**B, **9**D, and **9**E, when the engine output Pe becomes Pe_1 at time t_8, the generated power of the first motor generator **50** becomes Pg_4 such that the absolute value Pg_4 becomes equal to the absolute value of the power supply Pmt supplied to the second motor generator **60**. In other words, the generated power Pg of the first motor generator **50** and the power supply Pm supplied to the second motor generator **60** are in a balanced state. Accordingly, the actual boost voltage VHr sensed by the high-voltage sensor **85** is maintained at the target boost voltage VH_1 after reaching at the target boost voltage VH_1 at time t_8.

When the accelerator pedal of the hybrid vehicle **100** is pressed by the driver at time t_9 in FIGS. **9**A to **9**E, similarly to at time t_4 in FIGS. **4**A to **4**E, the controller **90** outputs commands to increase the motor torque Tm of the second motor generator **60** and the engine torque Te of the engine **70**. As shown in FIG. **9**E, the engine output Pe increases in response to this command. Similarly to at time t_5 in FIG. **4**E, when the engine output Pe reaches the threshold Pe_5 at time t_{10} in FIG. **9**E and the actual boost voltage VHr is decreasing as shown in FIG. **9**B, the boost converter **20** is restarted as shown in step S**212** in FIG. **8** to return to a normal control.

As described above, with the hybrid vehicle **100** according to the present embodiment, it becomes possible to effectively improve the system efficiency of the hybrid vehicle **100** by reducing the generated power Pg of the first motor generator **50** (power generator) driven by the engine **70** to balance with the power supply Pm supplied to the second motor generator **60** (electric motor) such that the system fuel consumption rate Fs of the hybrid vehicle **100** is maintained, for a long period, below a level applied before the boost converter **20** was stopped. Further, in the present embodiment, because the engine output Pe is temporarily reduced after the boost converter **20** is stopped, and then increased based on the deviation of the actual boost voltage VHr sensed by the high-voltage sensor **85** from the target boost voltage VH_1 so as to balance between the generated power Pg of the first motor generator **50** and the power supply Pm supplied to the second motor generator **60** to maintain the DC high voltage VH at a constant level, the DC high voltage VH can be maintained at a constant level by using a minimum required engine output Pe, restoring the loss of the system of the hybrid vehicle **100** as a whole to the minimum level. Further, when the actual boost voltage VHr continues to increase, the boost converter **20** is restarted to perform a normal operation in which the regenerative power output from the second motor generator **60** can be charged to the battery **10**. Therefore, the delay in the regenerative brake can be restricted, and drivability can be ensured.

The present invention is not limited to the above embodiments. Various changes and modifications within the technical scope or essential spirit of the present invention defined in the claims are considered to be included in the present invention. For example, the configuration of the hybrid vehicle **100** is not limited to the configuration described with reference to FIG. **1** in which the output of the engine **70** is distributed to the first motor generator **50** and the output shaft **73** by the motive power distribution mechanism **72** and the second motor generator **60** is connected to the output shaft **73**, but as shown in FIG. 20 in JP 2011-15603 A, the hybrid vehicle may have a configuration in which a power generator driven by an engine and an electric motor for driving the vehicle are provided, and a clutch is provided between the power generator and the speed-changing gears. The present invention may also be applied to a hybrid vehicle having a so-called "series-hybrid" driving mechanism in which a power generator for driving the vehicle is provided and an engine or a power generator driven by an engine is also provided independently from the vehicle driving mechanism. Further, although the above embodiments according to the present invention describe that the boost converter **20** is stopped when the battery current IB sensed by the battery current sensor **83** becomes equal to or below the threshold I_0, because the electric power output from the battery **10** (battery voltage VB×battery current IB) is equal to the electric power passing through the reactor **12** (DC low voltage VL×reactor current IL), and the battery voltage VB is equal to the DC low voltage VL at both ends of the filter capacitor **11**, the boost converter **20** may be stopped when, in the place of the battery current IB, the reactor current IL sensed by the reactor current sensor **84** is equal to or below the threshold I_0.

What is claimed is:

1. A hybrid vehicle comprising:
a battery;
a boost converter connected to the battery;
a first inverter connected to the boost converter;
a second inverter connected to the boost converter and the first inverter;
a power generator connected to the first inverter;
an electric motor connected to the second inverter;
an engine capable of driving the power generator; and
a controller which starts and stops the boost converter,
wherein the controller stops the boost converter when electric power transferred between the battery and the boost converter is equal to or below a predetermined threshold, and drives the power generator by the engine when an actual boost voltage of the boost converter reaches a predetermined threshold.

2. The hybrid vehicle according to claim **1**, wherein
the controller comprises an engine output adjustment unit which changes an engine output in accordance with a deviation of the actual boost voltage of the boost converter from a target boost voltage.

3. The hybrid vehicle according to claim **1**, wherein
the controller comprises a boost converter restart unit which restarts the boost converter when the actual boost voltage does not increase even with increase in engine output.

4. The hybrid vehicle according to claim **2**, wherein
the controller comprises a boost converter restart unit which restarts the boost converter when the actual boost voltage does not increase even with increase in engine output.

5. A hybrid vehicle comprising:
a battery;
a boost converter connected to the battery;
a first inverter connected to the boost converter;
a second inverter connected to the boost converter and the first inverter;
a power generator connected to the first inverter;
an electric motor connected to the second inverter;
an engine capable of driving the power generator; and
a controller which comprises a CPU and starts and stops the boost converter,
wherein the controller executes, using the CPU, a boost converter stop program which stops the boost converter when electric power transferred between the battery and the boost converter is equal to or below a predetermined threshold, and drives the power generator by the engine when an actual boost voltage of the boost converter reaches a predetermined threshold.

6. A control method of a hybrid vehicle comprising:
a battery;
a boost converter connected to the battery;
a first inverter connected to the boost converter;
a second inverter connected to the boost converter and the first inverter;
a power generator connected to the first inverter;
an electric motor connected to the second inverter; and
an engine capable of driving the power generator,
wherein the boost converter is stopped when electric power transferred between the battery and the boost converter is equal to or below a predetermined threshold, and the power generator is driven by the engine when an actual boost voltage of the boost converter reaches a predetermined threshold.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,272,704 B2
APPLICATION NO. : 14/592349
DATED : March 1, 2016
INVENTOR(S) : Ryoji Sato and Masayoshi Suhama

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Specification

In Column 1, Line 52, delete "**Ina**" and insert --**In a**--, therefor.

In Column 11, Line 41, after "Pe is not over the threshold", delete "**Pas**" and insert --$\mathbf{Pe_5}$--, therefor.

In Column 12, Line 52, after "which the engine output is at", delete "**Pea**" and insert --$\mathbf{Pe_3}$--, therefor.

In Column 14, Line 17, before "in FIGS. 9C and 9E", delete "$\mathbf{OP_5}$" and insert --$\mathbf{OP_7}$--, therefor.

In Column 15, Line 47, before "and determines whether", delete "**Pee**" and insert --$\mathbf{Pe_8}$--, therefor.

In Column 16, Line 17, after "Pe becomes", delete "$\mathbf{Pe_1}$" and insert --$\mathbf{Pe_7}$--, therefor.

Signed and Sealed this
Twenty-fourth Day of May, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office